# Universal scalar fit

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# Outline

- Global fit to all available pre-Moriond Brout-Englert-Higgs (BEH) boson data from the LHC and Tevatron

- Implications for the SM and beyond

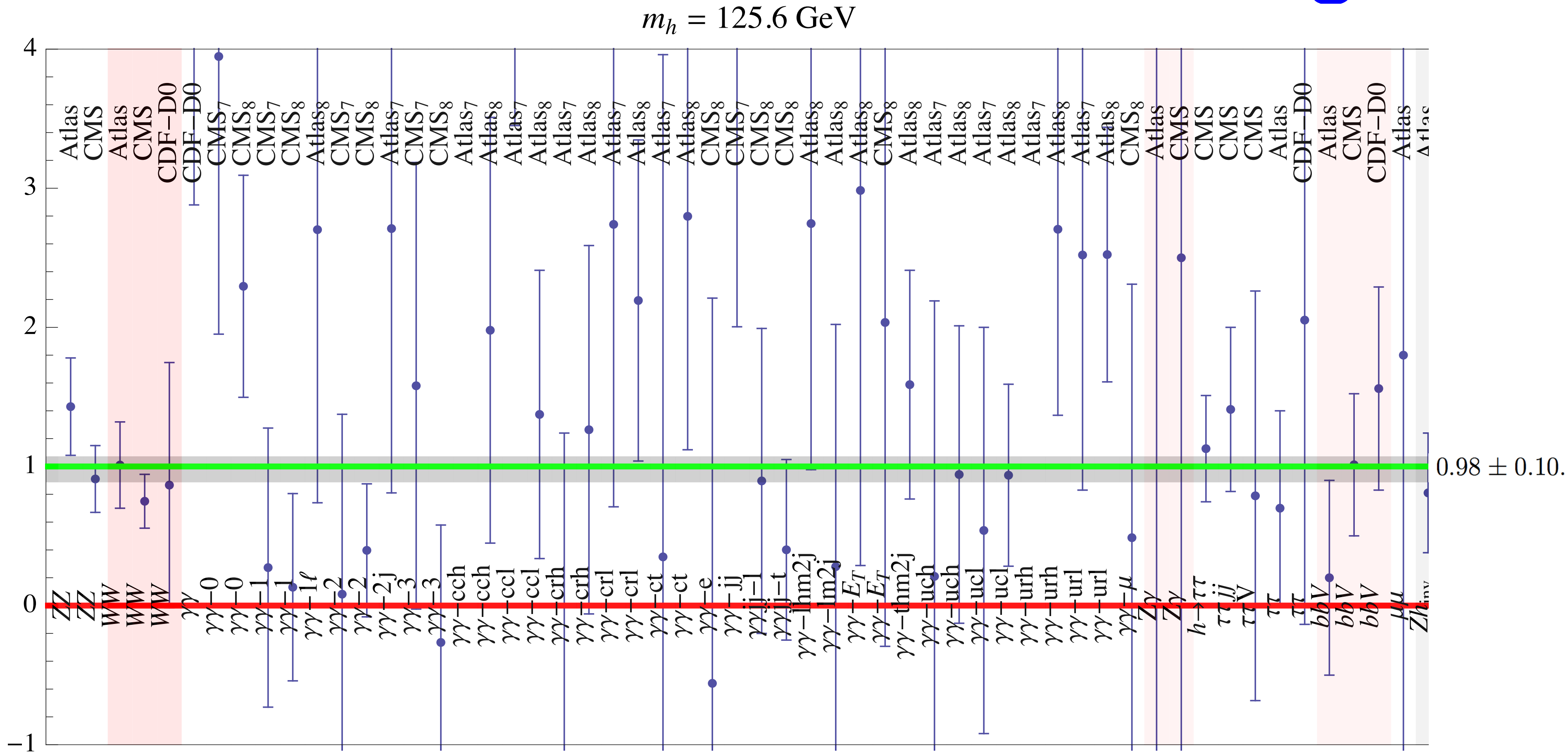
# The most striking LHC discovery so far – "a" scalar boson

- New boson discovered at 125-126 GeV by both ATLAS and CMS experiments
- Probably spin 0 and positive parity

  - Does an EW scale elementary scalar exist in Nature?

- Study its couplings to fermions and bosons!

# All LHC + Tevatron data - 10σ signal




P. Giardino, K. Kannike, I. Masina, M. Raidal, A. Strumia, arXiv:1303.3570

# Global fit to the data

Experiments report the measured rates as $R^{\rm exp} \pm R^{\rm err}$

$$\chi^2 \; = \; -2\ln\mathcal{L} \qquad \chi^2 = \sum_I \frac{(R_I^{\rm exp} - R_I^{\rm th}(\sigma_j))^2}{(R_I^{\rm err-exp})^2} + \sum_j \frac{(\sigma_j - \sigma_j^{\rm th})^2}{(\sigma_j^{\rm err})^2},$$

$$\sigma(pp \to h)_{\rm th} = (19.4 \pm 2.8)\,{\rm pb}, \qquad \sigma(pp \to jjh)_{\rm th} = (1.55 \pm 0.04)\,{\rm pb},$$
$$\sigma(pp \to Wh)_{\rm th} = (0.68 \pm 0.03)\,{\rm pb}, \qquad \sigma(pp \to Zh)_{\rm th} = (0.39 \pm 0.02)\,{\rm pb},$$
$$\sigma(pp \to t\bar{t}h)_{\rm th} = (0.128 \pm 0.018)\,{\rm pb} \qquad \text{at } \sqrt{s} = 8\,{\rm TeV}.$$

Allow couplings do deviate from the SM

$$\mathcal{L}_h \;=\; r_t \frac{m_t}{V} h\bar{t}t + r_b \frac{m_b}{V} h\bar{b}b + r_\tau \frac{m_\tau}{V} h\bar{\tau}\tau + r_\mu \frac{m_\tau}{V} h\bar{\mu}\mu + r_Z \frac{M_Z^2}{V} hZ_\mu^2 + r_W \frac{2M_W^2}{V} hW_\mu^+ W_\mu^- + $$
$$+ r_\gamma c_{\rm SM}^{\gamma\gamma} \frac{\alpha}{\pi V} hF_{\mu\nu}F_{\mu\nu} + r_g c_{\rm SM}^{gg} \frac{\alpha_s}{12\pi V} hG_{\mu\nu}^a G_{\mu\nu}^a + r_{Z\gamma} c_{\rm SM}^{Z\gamma} \frac{\alpha}{\pi V} hF_{\mu\nu}Z_{\mu\nu}.$$

$$\chi^2(r_t, r_b, r_\tau, r_W, r_Z, r_g, r_\gamma, r_{Z\gamma}, r_\mu, {\rm BR}_{\rm inv}),$$ 10 par.

# The universal scalar fit

## Data - NP can just be a small perturbation of SM

$$r_i = 1 + \epsilon_i \qquad \text{with} \qquad \epsilon_i \ll 1 \qquad \text{BR}_{\text{inv}} = \epsilon_{\text{inv}}.$$

$$\begin{aligned}
R_{h\to WW} &= 1 - 1.14\epsilon_b + 1.58\epsilon_g - \epsilon_{\text{inv}} - 0.04\epsilon_t + 1.72\epsilon_W + 0.02\epsilon_Z - 0.13\epsilon_\tau \\
R_{h\to ZZ} &= 1 - 1.14\epsilon_b + 1.58\epsilon_g - \epsilon_{\text{inv}} - 0.04\epsilon_t - 0.28\epsilon_W + 2.02\epsilon_Z - 0.13\epsilon_\tau \\
R_{h\to \tau\tau} &= 1 - 1.14\epsilon_b + 1.58\epsilon_g - \epsilon_{\text{inv}} - 0.04\epsilon_t - 0.28\epsilon_W + 0.02\epsilon_Z + 1.87\epsilon_\tau \\
R_{h\to \gamma\gamma} &= 1 - 1.14\epsilon_b + 1.58\epsilon_g - \epsilon_{\text{inv}} - 0.04\epsilon_t - 0.45\epsilon_W - 0.06\epsilon_Z - 0.13\epsilon_\tau + 2\epsilon_\gamma \\
R_{h\to bb} &= 1 + 0.86\epsilon_b + 1.58\epsilon_g - \epsilon_{\text{inv}} - 0.04\epsilon_t - 0.28\epsilon_W + 0.02\epsilon_Z - 0.13\epsilon_\tau \\
R_{V(h\to bb)} &= 1 + 0.86\epsilon_b - 0.17\epsilon_g - \epsilon_{\text{inv}} - 0.05\epsilon_t + 0.83\epsilon_W + 0.67\epsilon_Z - 0.13\epsilon_\tau,
\end{aligned}$$

$$\chi^2 = \sum_{i,j} (\epsilon_i - \mu_i)(\sigma^2)^{-1}_{ij}(\epsilon_j - \mu_j), \qquad \text{where} \qquad (\sigma^2)_{ij} = \sigma_i \rho_{ij} \sigma_j$$

$$\begin{aligned}
\epsilon_b &= -0.23 \pm 0.31 \\
\epsilon_g &= -0.25 \pm 0.25 \\
\epsilon_{\text{inv}} &= -0.20 \pm 0.26 \\
\epsilon_W &= -0.14 \pm 0.14 \\
\epsilon_Z &= +0.00 \pm 0.13 \\
\epsilon_\gamma &= -0.02 \pm 0.16 \\
\epsilon_\tau &= +0.00 \pm 0.19
\end{aligned}
\qquad
\rho = \begin{pmatrix}
1 & 0.75 & 0.17 & 0.45 & 0.39 & 0.53 & 0.45 \\
0.75 & 1 & 0.52 & 0.32 & 0.19 & 0.39 & 0.32 \\
0.17 & 0.52 & 1 & 0.55 & 0.41 & 0.51 & 0.40 \\
0.45 & 0.32 & 0.55 & 1 & 0.67 & 0.69 & 0.60 \\
0.39 & 0.19 & 0.41 & 0.67 & 1 & 0.60 & 0.54 \\
0.53 & 0.39 & 0.51 & 0.69 & 0.60 & 1 & 0.58 \\
0.45 & 0.32 & 0.40 & 0.60 & 0.54 & 0.58 & 1
\end{pmatrix}$$

# Results from fits

# The boson mass

$$M_h = 125.66 \pm 0.34 \ \text{GeV} = \begin{cases} 125.4 \pm 0.5_{\text{stat}} \pm 0.6_{\text{syst}} & \text{GeV} \quad \text{CMS } \gamma\gamma \\ 125.8 \pm 0.5_{\text{stat}} \pm 0.2_{\text{syst}} & \text{GeV} \quad \text{CMS } ZZ \\ 126.8 \pm 0.2_{\text{stat}} \pm 0.7_{\text{syst}} & \text{GeV} \quad \text{ATLAS } \gamma\gamma \\ 124.3 \pm 0.6_{\text{stat}} \pm 0.4_{\text{syst}} & \text{GeV} \quad \text{ATLAS } ZZ \end{cases}$$

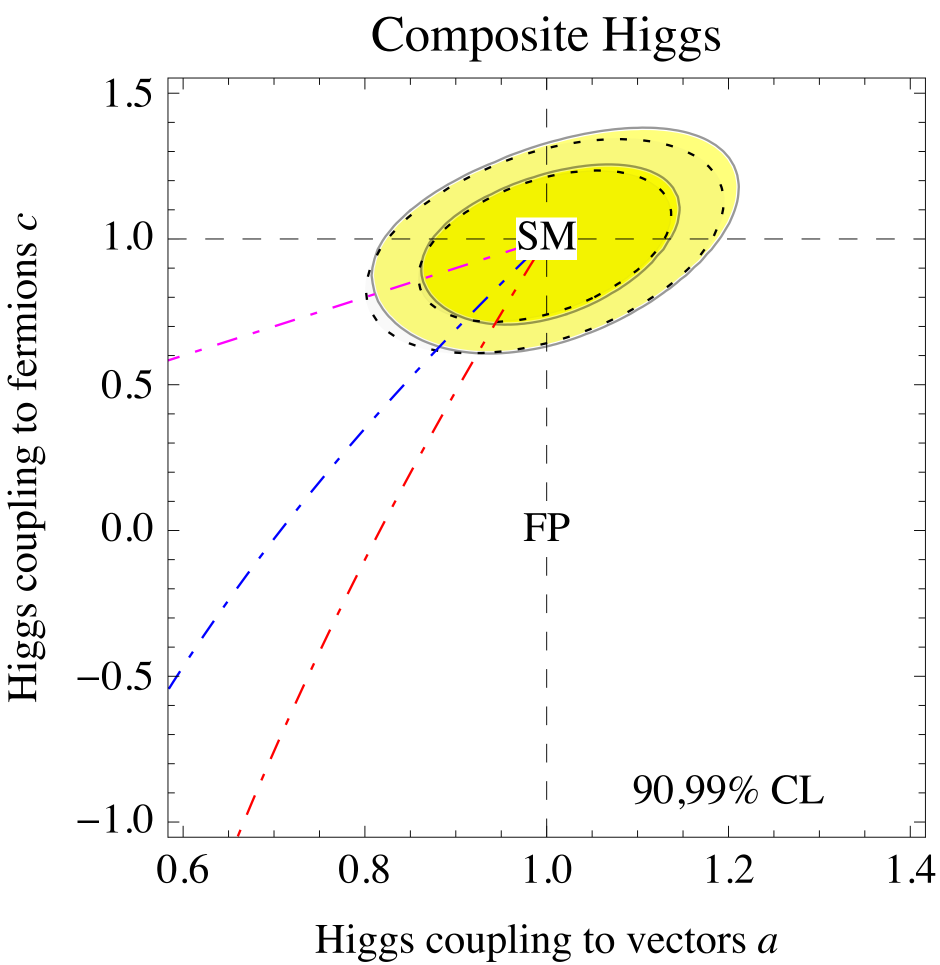
Indirect BEH boson mass measurement from rates, assuming the SM

$$\sigma(pp \to X) \approx \sigma(pp \to X)_{M_h = 125\,\text{GeV}} \times [1 + c_X \times (M_h - 125\,\text{GeV})].$$

$$M_h = 124.5 \pm 1.7 \ \text{GeV}$$

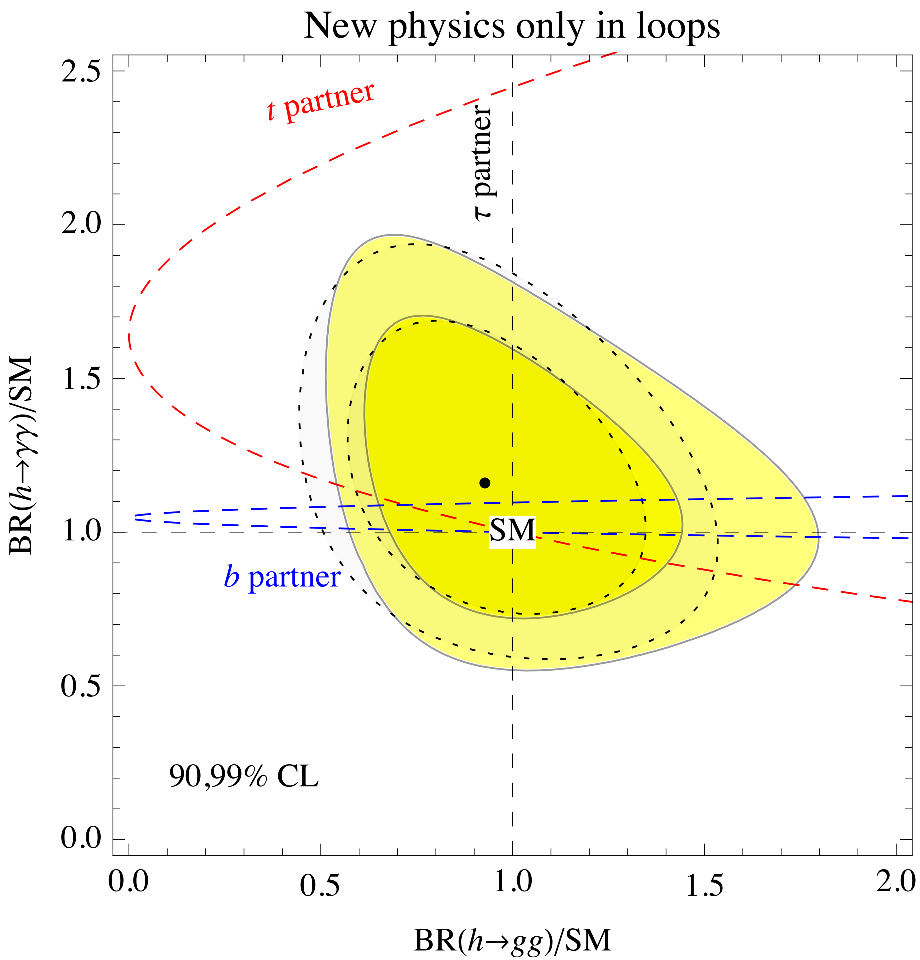
# Tests of couplings to bosons and fermions

$$r_t = r_b = r_\tau = r_\mu = c, \qquad r_W = r_Z = a.$$



# New physics enters only in loops

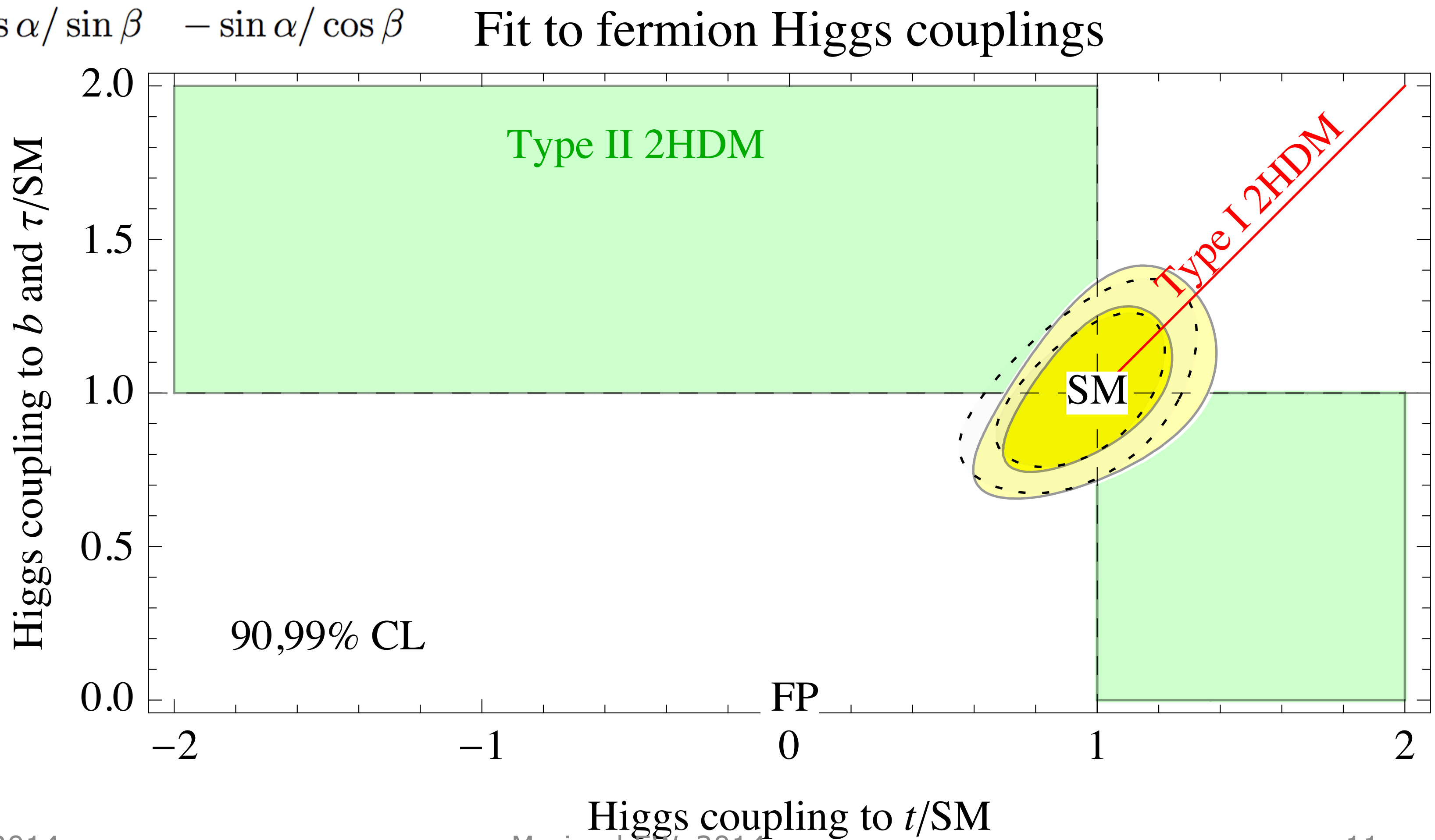
$$r_t = r_b = r_\tau = r_\mu = r_W = r_Z = 1, \qquad \frac{\Gamma(h \leftrightarrow gg)}{\Gamma(h \leftrightarrow gg)_{\rm SM}} = r_g^2, \qquad \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{\rm SM}} = r_\gamma^2$$



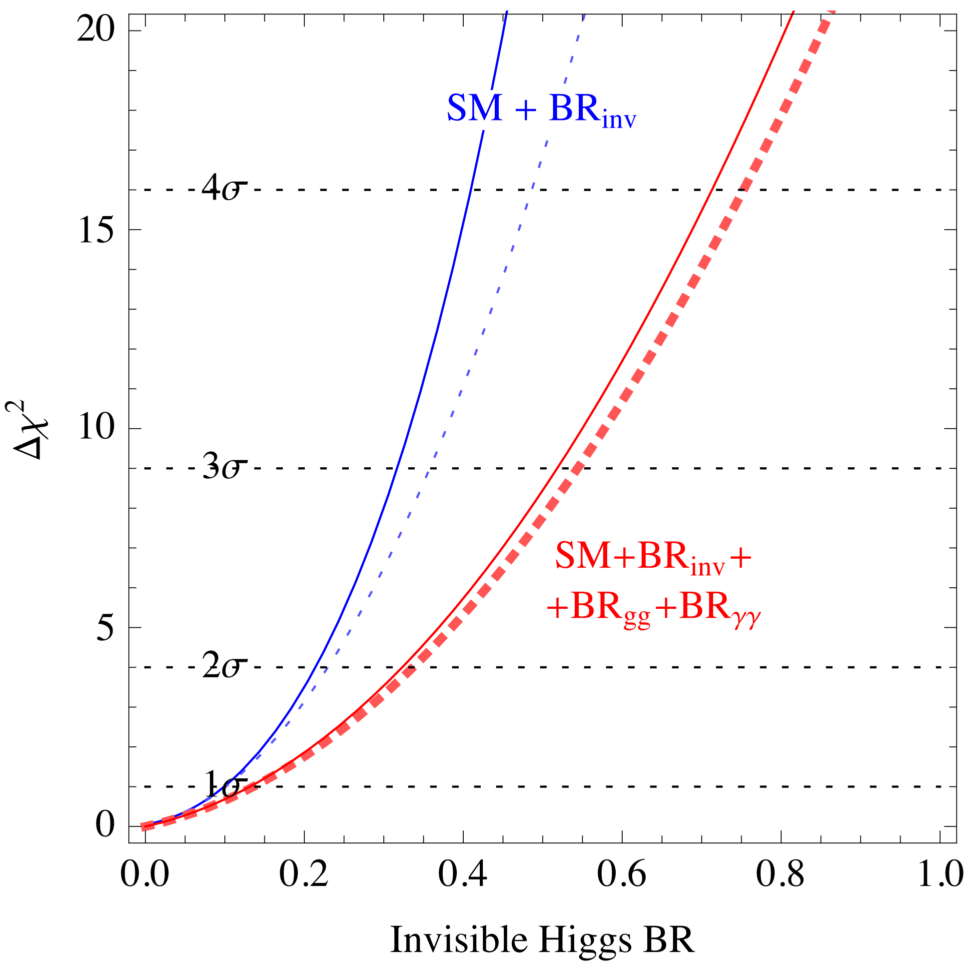
# Extra scalar doublet - 2HDM

| | Type I | Type II |
|---|---|---|
| $r_t$ | $\cos\alpha/\sin\beta$ | $\cos\alpha/\sin\beta$ |
| $r_b$ | $\cos\alpha/\sin\beta$ | $-\sin\alpha/\cos\beta$ |
| $r_\tau$ | $\cos\alpha/\sin\beta$ | $-\sin\alpha/\cos\beta$ |

$$r_W = r_Z = \sin(\beta - \alpha).$$



# BEH boson invisible width




SM+BR$_{inv}$

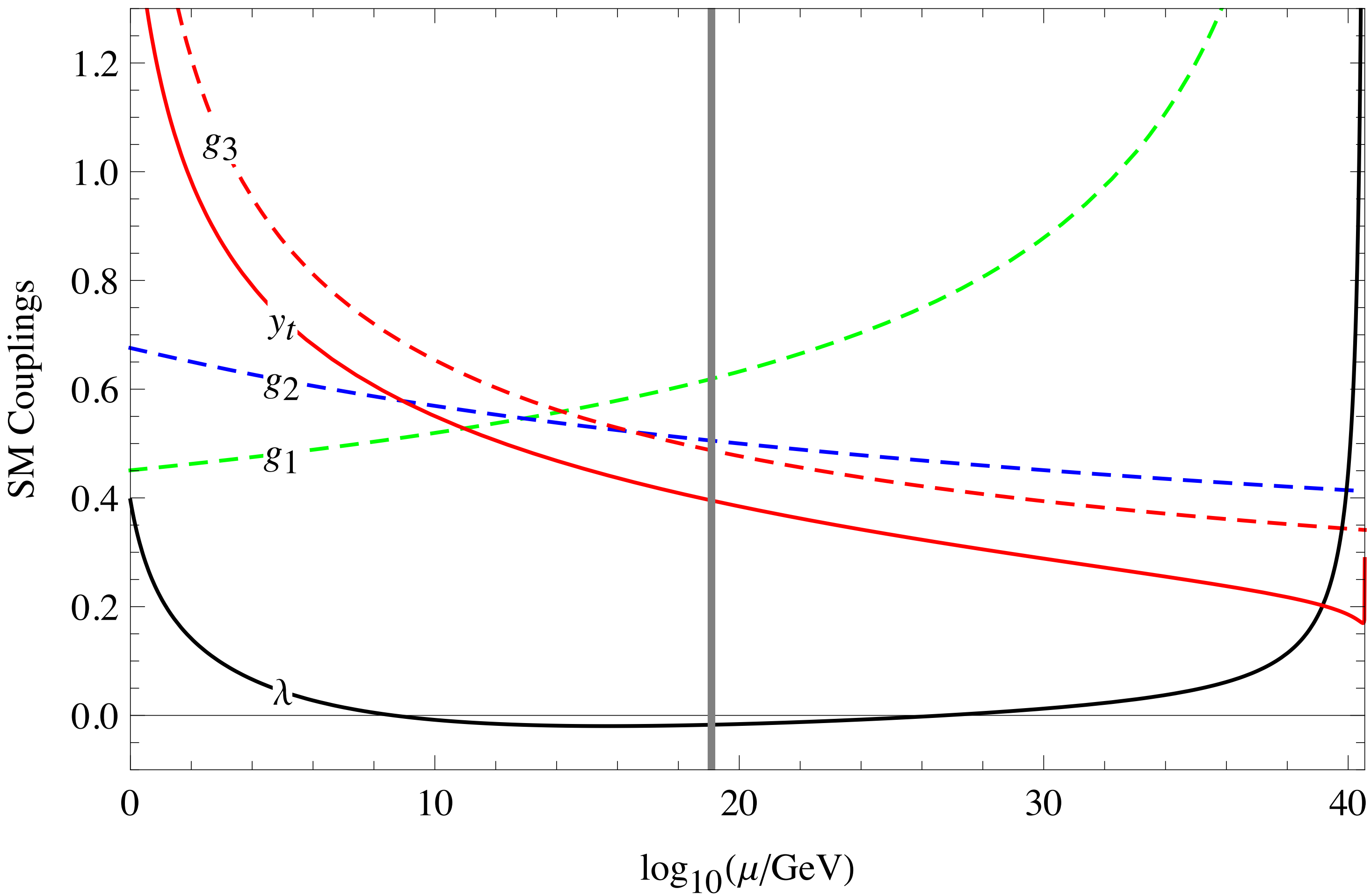
$$BR_{inv} < 0.24 \text{ at } 95\% \text{ C.L.}$$

SM+BR$_{inv}$+loops

$$BR_{inv} < 0.34 \text{ at } 95\% \text{ C.L.}$$

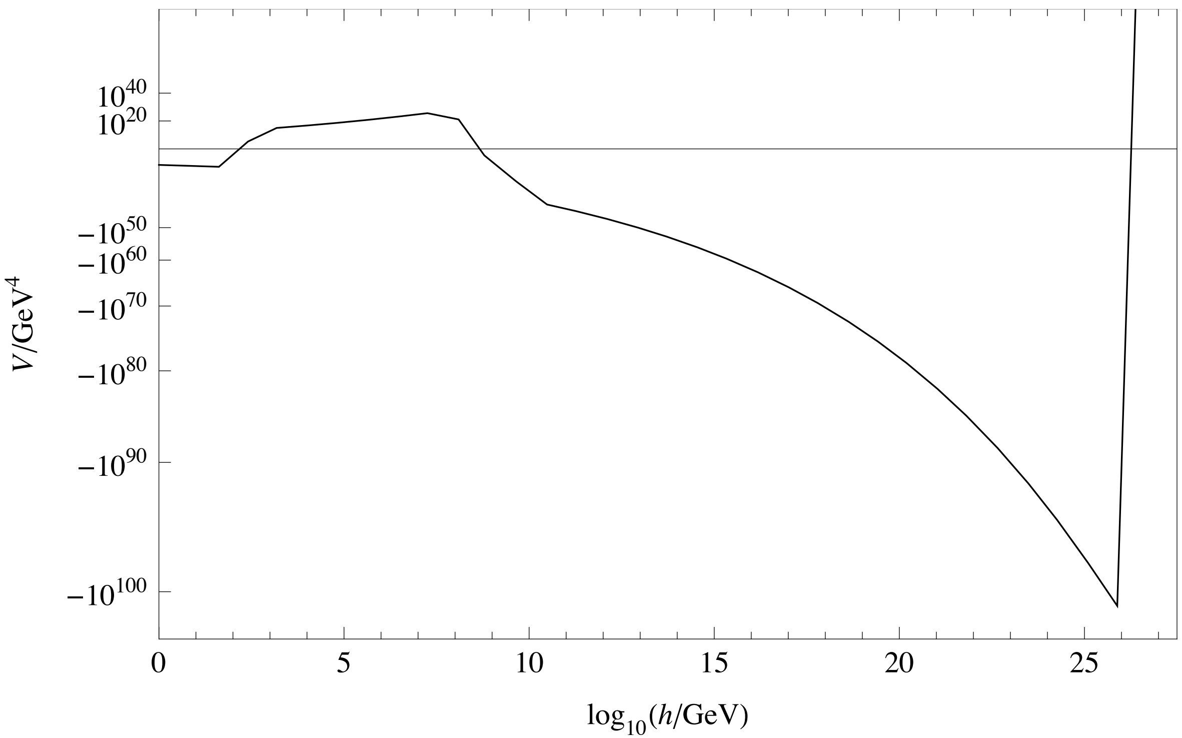
Experimental results are consistent with the elementary SM BEH boson

# The SM couplings in the full validity range




arXiv:1309.6632

# The SM Higgs potential is unstable




- Top Yukawa plays the most important role in scalar potential

- Lifetime of our metastable vac. is sufficient

- Why do not we live in the global minimum?

The LHC and cosmology are teaching us a lesson

Do we take the message seriously?

# Experimental results in last 40 years

- SM+$\nu_R$ - elementary scalar H at the EW scale
- Inflation, $V^{1/4} \approx 10^{16}$ GeV, $\varphi$ field values far above $M_P$
- Dark Matter – only gravitational evidence so far
- Dark Energy – too small for any particle threshold

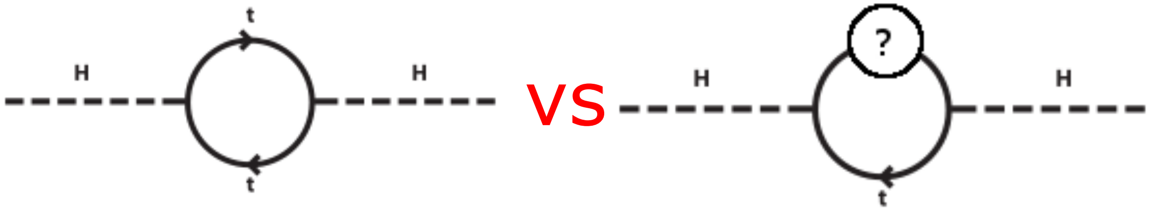
- No clear evidence for new physics from precision data, flavour physics, collider physics, no LFV, no EDMs, no evidence for higher order operators etc.

# Logical possibilities for NP

- NP repeats some of the features of the SM
  - Compositeness, technicolor copy QCD
- NP follows completely new physical principles
  - Infinitely many known/unknown possibilities
  - An example is the supersymmetry
- The SM is NOT the low energy EQFT of some fundamental QFT but is fundamental itself
  - SM+singlets ($\nu_R$,S) explain all exp. results and scales
  - Hierarchy problem?
  - Renormalizability?

# Natruralness – physical guiding principle

- Does BEH scalar imply the hierarchy problem?




$M_H^2 \propto M^2 \log(\Lambda/M)$

- Quadratic divergence problem does not exist!
- All new particles must interact weakly with the SM
- Gravity – case of special interest!
  - UV theory of gravity is not known – examples exist where UV gravity becomes non-local without particle threshold
  - UV theory of gravity is NOT EQFT with all non-ren. op.
  - QCD, EW, Planck scale etc. do NOT contribute to DE

# What replaces Wilsonian picture of renormalization?

- If SM+singlets is the final theory, Wilsonian picture of suppression of higher order operators is lost
- Classical scale invariance as fundamental law of nature may explain why the SM is renormalizable
- All scales generated via dimensional transmutation
- Classical scale invariance does not solve the hierarchy problem
  - Scales may be generated by dimensional transmutation, all previous arguments apply

# Conclusions

# Particle physics in last 40 years

# Conclusions

- Data prefers elementary BEH boson
- All known exp. results of physics beyond the SM can be explained with singlets
- Naturalness and minimalism as guiding principles suggest for paradigm shift in particle physics

Is the SM+singlets the ultimate QFT?